CLIMATE RISK PROFILE SERIES

ADAPTING GREEN INNOVATION CENTRES TO CLIMATE CHANGE: ANALYSIS OF VALUE CHAIN ADAPTATION POTENTIAL

Tomato, potato and apple value chains in Himachal Pradesh, Karnataka, Maharashtra and Andhra Pradesh, **India**


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CGIAR RESEARCH PROGRAM ON Climate Change, Agriculture and Food Security CCAFS

ABOUT THIS REPORT

Climate change is affecting agriculture more than any other sector. Increased frequency and severity of drought, flood, heat, and unseasonable rainfall heavily impact rainfed agriculture, ultimately resulting in production losses. In that context, The Alliance of Bioversity International and the International Center for Tropical Agriculture (CIAT) through its climate action lever, are developing climate risk profiles for agricultural value chains in developing countries at the national and subnational level. These profiles build on past work conducted by CIAT and the CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)in collaboration with the World Bank and other partners, including FAO, USAID, DFID[1].

The present report aims to provide a climate and vulnerability analysis of the Green Innovation Centres (GIC) target commodity value chains. Herein we identify climate change- related vulnerabilities, hazards, and opportunities for adaptation to the same. Ultimately, our goal is to foster awareness of risks and adaptation priorities in the selected value chains and inform climate investments and planning through the recommendations on priority innovations to manage climate risks.

The report begins with an extensive literature reviews of the selected value chains and their key challenges and adaptation strategies. Climate hazards and crop suitability modelling offer insights into potential future scenarios under climate change. These results inform potential adaptation approaches, which are prioritized by in-country experts and stakeholders through an online survey. The top-rated adaptation priorities undergo a cost-benefit analysis. Finally, the results are peer-reviewed by the GIC country office and the Alliance scientific staff.

The **Green Innovation Centres** for the Agriculture and Food Sector (GIC) founded by German Federal Ministry for Economic Cooperation and Development (BMZ) and led by the German Agency for International Cooperation (GIZ) in collaboration with local ministries and programmes, aims to promote agricultural innovation under the *ONEWORLD No Hunger* initiative. Through the GIC, GIZ aims to generate employment raise farmers' income, and improve farmers' education and skills by funding training in good agricultural practices, water management, post-harvest processing, and entrepreneurship.

Planning, data collection and stakeholder engagement
- Literature review (key documents and datasets)

Climate risk assessment
- Hazard analysis
- Crop suitability modelling

Identification of adaptation strategies
- Detailed review
- Gap analysis and identification of climate adaptation
- Online survey
- CBA analysis

Production of the country climate profile and validation
- Peer-review

1 https://ccafs.cgiar.org/publications/csa-country-profiles

HIGHLIGHTS

- India's agricultural sector employs 70% of the population and contributes 18% to the Gross Domestic Product (GDP) **(Chapter 2, pg.8).**
- Smallholders constitute 86% of India's total production, and agricultural products constitute 50% of total exports **(Chapter 2, pg. 9&11).**
- Despite the role women play in value chains, religious restrictions and customary laws restrict their access to resources such as land tenure, making them less economically viable and more vulnerable climate change impacts **(Chapter 2, pg.12).**
- Through collaborations with the private sector, and the formulation of policies, plans and frameworks for managing climate change, the Government of India (GOI) has made efforts in strengthening the adaptive capacity of farmers. Financial constraints, limited coordination, and weak monitoring systems cause inefficient policy implementation **(Chapter 3, pg. 18).**
- Potato, tomato, and apple value chains are affected by climatic hazards such as high temperatures, late onset of rains, hailstorms, and drought **(Chapter 5, pg. 21).**
- Adaptation strategies that manage climatic hazard effects include climatically adapted cultivars, precision irrigation, water saving solutions, protected cultivation, planting date adjustments, anti-hail nets, and high density plantations **(Chapter 6, pg. 31-32).**
- Adaptation is limited by unreliable weather information, limited storage and value addition/processing facilities, inadequate credit and marketing facilities, and poor technology adoption **(Chapter 6, pg. 31).**
- Conclusively the adaptation potential for the selected value chains is promising. A Cost Benefit Analysis (CBA) demonstrates that the use of drip irrigation is a profitable adaptation strategy that increases productivity during drought. It however has a low to moderate investment that requires high capital for installation, maintenance, and operations **(Chapter 6, pg. 37-38).**

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ACRONYMS AND ABBREVIATIONS

APMC	Agricultural Produce Market Committee
CBA	Cost-Benefit Analysis
CAPE	Country Assistance Programme Evaluation
CIAT	International Centre for Tropical Agriculture
CSA	Climate Smart Agriculture
GAP	Good Agricultural Practices
GDP	Gross Domestic Product
GIC	Green Innovation Centres
GIZ	German Agency for International Cooperation
GOI	Government of India
GPI	Gender Parity Index
HDP	High Density Plantation
IARI	Indian Agricultural Research Institute
IRR	Internal Rate of Returns
MOA&FW	Ministry of Agriculture and Farmers Welfare
MOEFCC	Ministry of Environment, Forest and Climate Change
NHRDF	National Horticultural Research and Development Foundation
NIAM	National Institute of Agricultural Marketing
NIC	National Intelligence Council
NPV	Net Present Value
OWFI	One World Foundation India
RACP	Rajasthan Agricultural Competitiveness Project
USD	United States Dollar

1. INTRODUCTION

India's agricultural sector is vulnerable to climate change due to overpopulation, increased food demand, and natural resource degradation. Over the past three decades, there has been observed climatic changes including increasing temperature, variability in rainfall, hailstorms, frost, and prolonged drought. Climatic changes create negative consequences like soil degradation, water shortages, and declining farm productivity. Climate change decreases annual agricultural production by 4–9%, which results in a 1.5% loss in the GDP (Rattani, 2018). Regional impacts differ, yet future climate projections show that trends will persist in the coming decades. For instance, mean temperatures will rise by 0.5°C by the year 2030. Therefore, government efforts should build the adaptive capacity of farmers to improve their livelihood and food security.

Women play an essential role in the Indian agricultural sector, and are involved in value chain activities, especially labour provision. However, religious sanctions, traditional beliefs, and restriction to economic resources hinder their contribution to agriculture. Capacity building through training and extension programmes need to be accessible to women. The National Action Plan on Climate Change (2008) is the main policy that presides over climate change initiatives in India. Implementation is impeded by lack of technical expertise, a weak monitoring system, poor intra-governmental coordination, and financial constraints. Consequently, the goal of strengthening farm community resilience has yet to be achieved.

India's Ministry of Agriculture and Farmers' Welfare (MoA&FW) has collaborated with the German Agency for International Cooperation (GIZ) to execute the Green Innovation Centres (GIC) Agricultural and Food Sector Project. The GICs project was implemented by Karnataka, Maharashtra, Andhra Pradesh and Himachal Pradesh. The project's goal is to strengthen the potato, tomato, and apple value chains by building farmer capacity, improving services and structures, and enhancing knowledge exchange. This project will sustainably increase productivity, create employment opportunities, and boost smallholder incomes.

This document presents India's climate risk profile. The profile's aim is to inform the government and value chain stakeholders of climatic hazards and prioritized Climate Smart Agriculture (CSA) practices and will integrate climate change in the national development agenda. The document is a collaboration with the International Center for Tropical Agriculture (CIAT), now part of the Alliance of Biodiversity International and CIAT.

Information was collected through a literature review and expert interviews from the potato, apple and tomato value chains. This profile has six sections, beginning with the importance of agriculture to the livelihoods of Indian households. The second section discusses policies, strategies, and programmes for climate change, while the third section is on governance, institutional, and resource capacities. The climate change-related risks and vulnerabilities in the three value chains are in the fourth section, followed by the climate change adaptation strategies, and a cost benefit analysis in the fifth section. Finally, the synthesis of the report and recommendations are highlighted in the last section.

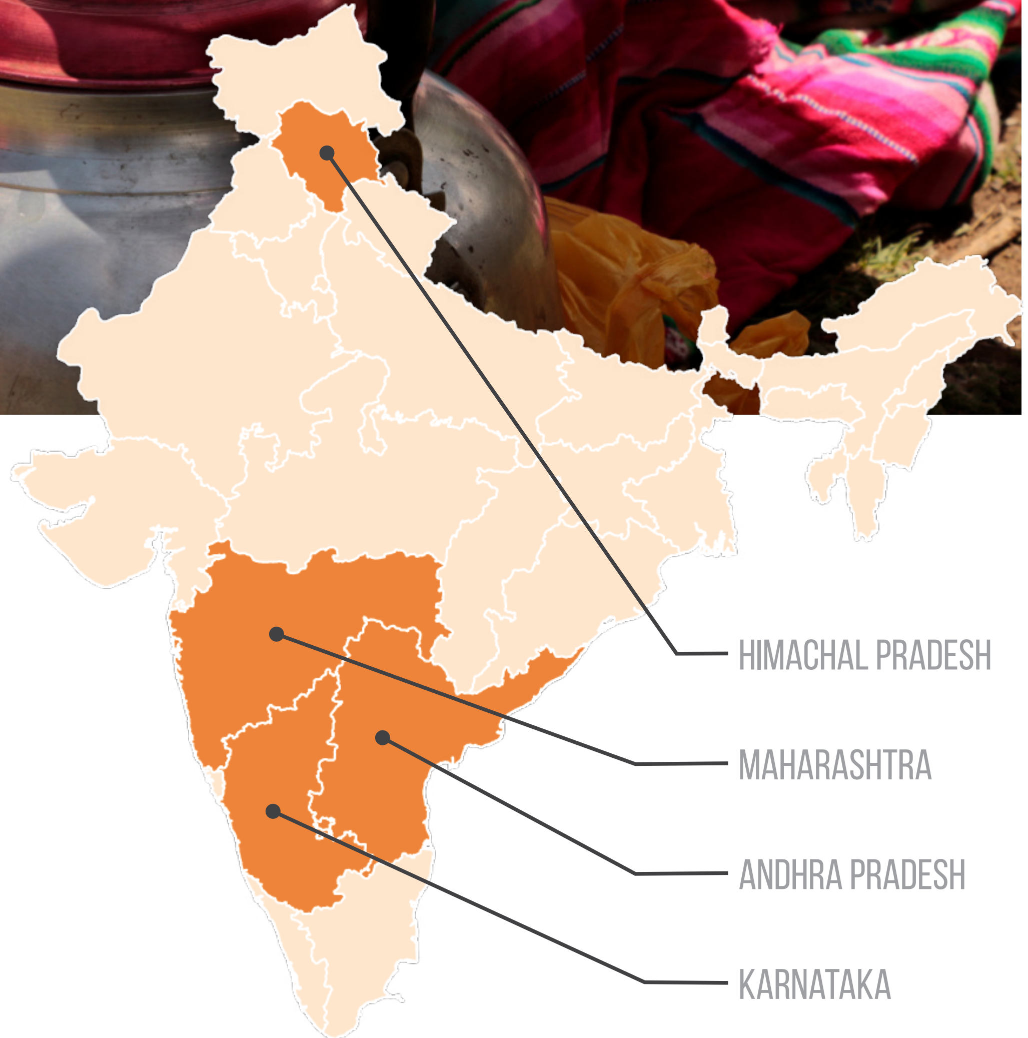


Figure 1. Map of India showing GICs areas of operation

India lies in Southern Asia, sharing land borders with Pakistan and Afghanistan to the North West; China, Bhutan, and Nepal to the North, and Myanmar and Bangladesh to the East.

2. AGRICULTURAL CONTEXT

KEY MESSAGES

» India is mainly an agricultural economy, employing a majority of the country's workforce, and significantly contributing to the national income and food stock.

» India has experienced a rapid growth in agricultural trade due its global dominance in milk, fresh vegetables and food grains production.

» Presented with climate variability, high population growth and poverty rates, and agricultural sector challenges, there is need for innovations on climate smart practices.

» The potato, tomato and apple value chains have been highlighted due their significance in India's agricultural sector.

2.1. Economic relevance of farming

India is the seventh largest country in the world, covering a land area of 3.287 million km². Administratively, India has 7 union territories and 29 states, which are further divided into districts (GOI, 2011).

India is an agricultural economy, providing a livelihood to 70% of the country's population. The sector contributes to about one sixth of the national income, which represents 18% of the Gross Domestic Product (GDP) (Sakhare, 2017). It is estimated that agriculture contributes to more than 300 billion United States Dollars (USD) to India's GDP (CAPE, 2017). Between 2013-2014, agriculture and allied sectors including fisheries, agribusiness, domesticated animals, and ranger services had an aggregate share of 13.9% of the GDP (Madhusudhan, 2015). Close to 56% of India's work force is employed in the agriculture sector. Women form an integral part of the agricultural labour force. Four fifths of economically active women (Ghosh & Ghosh, 2014) and 86% of rural women are employed in the sector (Yadav et al., 2016).

India's food stock is currently estimated at 50 million tons (CAPE, 2017). India is the largest global producer of rice, pulses, wheat, spices and spice products, and the second largest producer of fruits and vegetables (Madhusudhan, 2015). Other food crops such as maize and millet are extensively grown in India. Sugarcane, cotton, jute, tobacco, and oilseeds are widely grown as cash crops. Additionally, plantation crops like coffee, tea, coconut, and rubber are cultivated throughout India (Goverdhan, 2015). The meat, dairy, poultry, and fisheries industries are also significant agribusiness sub sectors in the country (Madhusudhan, 2015).

Agricultural trade in India has recorded rapid growth over the past decade. Exports have an average annual growth rate of 15% (Cagliarini & Rush, 2011). Of the total exports in India, agricultural products constitute 50%. Rice, sugar, tea, tobacco, oilseeds, and spices are the main export commodities (Sakhare, 2017). Indian spice exportation is estimated at 3 billion USD (Madhusudhan, 2015) and the average trade value for rice is 2,137million USD (Cagliarini & Rush, 2011). In the past few decades, agricultural exports have surpassed imports. Supported by government policies such as the ban of import duties, India has been able to boost domestic food production, thus reducing the food shortage gap (CAPE, 2017).

Women play a pivotal role in the production of staple food crops and secondary crops like vegetables and pulses. They are also central in food crop activities such as breeding, selection, cultivation, harvesting, and preparation (Ghosh & Ghosh, 2014). In livestock production, women are involved in cleaning livestock and their structures, watering, milking, and milk processing. It is noted that marketing milk is entirely run by women whereby most rural women earn income from selling milk (Yadav et al., 2016). This could explain the dominance of women in dairy production. There are 75 million women compared to 15 million men in the milk value chain and 20 million women compared to 1.5 million men practicing animal husbandry in India (Ghosh & Ghosh, 2014).

2.2. People and livelihoods

According to the National housing and population census[2], India has a population of 1.2 billion people and a density of 382 persons per km². This depicts a 17.5% increase from the previous decade. Compared to the national population percentage, Maharashtra has the highest population (9.28%) among the four states followed by Andhra Pradesh at 6.99%, and Karnataka at 5.05%. Himachal Pradesh is the least populated at 0.57%. Women constitute 48.5% of the population while men are 52.5%, a percentage that is almost similar in all the four states. About 68.9% of India's population is concentrated in rural areas. Except for Himachal Pradesh, which has 90% of its population in the rural areas, the three other states have slightly more than 60% of people residing in rural areas.

The biggest challenge in rural India is poverty. Almost 89% of the population in the bottom 20% of the income quintile live in rural areas and are in abject poverty (Bisht et al., 2020). Between 2011-12, the rural poverty rate was 25.7% compared to an urban poverty rate of 13.7% (GOI, 2019). High poverty rates have further affected food access as reflected in food expenditures. For example, the poorest 30% of the population have the highest average share of food expenditures. In rural areas, this population group spends 60% of their income on food compared to 55% in urban areas (GOI, 2019). Therefore, rural economic improvement would increase farmer livelihood.

Two thirds of the female workforce and more than 50% of India's population is employed in agriculture. However, the amount of youthful in the workforce has declined. Lack of economic incentives forced young people to migrate to urban areas in pursuit of non-farm employment (Bisht et al., 2020). Localized marketing, capacity building, and strengthening local value of farm produce are interventions that can increase sustainability and profitability of rural farming. These interventions generate green jobs at the community level and incentivize youth's participation in agriculture.

The general standard of living of many households in India is poor. Households in urban areas have better access to basic resources compared to those in rural areas. For example, 58.7% of rural households have a principal source of drinking water inside their home compared to 80.7% in urban areas (GOI, 2018). Pucca[3] material constructed 76.7% of rural homes and 96% of urban homes. Over 90% of both urban and rural dwellers use electricity for domestic purposes. Liquefied Petroleum Gas (LPG) is used for cooking in 61.4% of India's households, while 31.2% of households use alternative sources like firewood, crop residue, and chips. However, there is access disparity whereby 48.3% of rural households use LPG compared to the 86.6% in urban areas. As a result, 44.5% of rural households use alternative sources compared to 5.6% of urban households.

2 The most recent housing and population census statistics for India is from 2011. Unless otherwise cited, all population statistics stated in text are from this report.

3 Pucca housing is an Indian term that refers to solid and permanent homes. In most instances, the houses are made of substantial material e.g. stone, brick, cement, concrete, or timber.

India has a high literacy[4] rate of 77.7%. While the literacy rate among men is higher at 84.7% compared to that of women at 70.3%, the Gender Parity Index (GPI)[5] is increasing, especially in higher education. The high literacy rate is attributed to government programmes that support equitable education (GOI, 2019b). India has a recurrent problem of malnutrition and food security despite its agricultural economy. Between 2015-16, 38.4% of children under the age of 5 were stunted and 35.7% were underweight. Malnutrition and stunted growth restrict physical development and lead to poor educational and economic attainment, which perpetuates poverty. Therefore, India must create policies that address malnutrition (GOI, 2019).

2.3. Agricultural activities

Agriculture is an important sector in India. Livestock and crop production are widespread, however, food crop production is dominant (Goverdhan, 2015). India has diverse agro-climate zones[6] that allow for crop diversification throughout the year. Himachal Pradesh and Andhra Pradesh lie in the Himalayan region, the West and East, respectively. Karnataka and Maharashtra lie in the plateau and hills region, the West and South, respectively (GOI, 2019).

India's agricultural producers are comprised of 86.2% smallholder farmers. Most of these smallholders own less than 2 ha, with each farmer owning an average of 0.6 ha of land. Medium and semi-medium scale farmers make up 13.2% that own land between 2-10 ha and occupy 43.6% of cropland (Bisht et al., 2020). Smaller and fragmented landholdings restrict marketable surplus production and farmers are unable to sustain their livelihoods. Thus, the majority of farmers in India practice subsistence farming (Goverdhan, 2015).

India has the second largest area of arable land in the world and is a major producer of milk, fresh vegetables, and food grains (Cagliarini & Rush, 2011). India has 1,820,100 km^2 of arable land, which accounts for 55% of the country's land area (GOI, 2011). Maharashtara has the highest percentage of arable land at 68.6%. Karnataka is 67% arable land and Andhra Pradesh is 57.5%. Himachal Pradesh has the least amount of arable land at 14.6%. Between 2015-2018, food grains occupied 124 million ha of land. Rice and wheat constituted 80% in volume of the food grains, with rice covering 27.2% and wheat covering 18.8% of the production area. They are followed by coarse cereals at 15.7% of production area and pulses at 17.4% of cropland (GOI, 2019). The total production of food grains between 2015-2016 was 252,224,000 tons, which rice constituted 41.4% and wheat 37.1%. Sugarcane and oil seeds are the leading commercial crops with a production of 35,2162,000 and 25,303,000 tons respectively. Andhra Pradesh leads in the production of food grains, followed by Karnataka and Maharashtra, while Himachal Pradesh has the lowest production quantities of all crops.

Livestock production is widely practiced in India. By 2012, India's livestock population was 512,057,000 and the country's poultry population was 729,209,000. Cattle production is the most practiced at 37.3%, goat production at 26.4%, and buffalo production at 21.2%. Andhra Pradesh is the leading livestock producer at 11%, Maharashtra at 6.3%, and Karnataka at 5.4%, while Himachal Pradesh is the smallest livestock producer at 0.9%. Between 2015-2018, India produced 165,404,000 tons of milk. Andhra Pradesh was the top milk producer at 7.3%, followed by Maharashtra at 6.3%, and Karnataka at 4.0%, while Himachal Pradesh produced the least milk at 0.8%. In the same period, India produced 881,386 Lakhs Nos[7] of eggs. Andhra Pradesh was the highest egg producing state at 18.3%, with Maharashtra at 6.2%, and Karnataka at 5.7%, while Himachal Pradesh produced the least amount of eggs at 0.1% (GOI, 2019).

Indian production systems are characterized by traditional cultivation techniques (Goverdhan, 2015). These systems do not use or minimally use modern farming equipment like tractors and inputs[8] such as chemical fertilizers and pesticides. Mixed cropping is also common, where farmers cultivate cereals along with other crops like pulses, oil seeds, vegetables, and sugarcane. There has been an increase in irrigation infrastructure. Andhra Pradesh has 62.5% of irrigated land, Karnataka has 28.2%, and Maharashtra has 16.4% of irrigated land (CAPE, 2017).

Women[9] make an essential contribution to the Indian agriculture sector through their engagement in major farm activities. However, women's roles in domestic chores, religious sanctions, and traditional beliefs that consider them homemakers are a hindrance to their effectiveness in various agricultural roles (Yadav et al., 2016). In addition, women do not have equal access to resources that could enhance their economic contribution to agriculture. India's customary laws allocate sole titles that could obtain production credits entirely to men (Behera & Behera, 2013). Moreover, agricultural development initiatives like mechanization tend to alleviate male dominated activities. Women need to be involved in agricultural development planning, training, and extension programmes to build their capacity.

2.4. Agricultural value chain commodities

For this climate risk profile, GIC identified three value chains to represent the economic, social and environmental challenges faced by Indian farmers. The potato, tomato, and apple value chains are hereby discussed.

2.4.1. Potatoes

India is the second largest potato producer globally. Potatoes are one of the main commercial crops in the country and are an important food crop. It is ranked fourth after rice, wheat and maize in terms of food crop production (RACP, 2013). The major potato growing states are Himachal Pradesh, West Bengal, Punjab, Uttar Pradesh, Maharashtra, Madhya Pradesh, Bihar Gujarat, Karnataka and Assam. However, 74% of total potato production is contributed by West Bengal, Bihar, and Uttar Pradesh (Rana & Anwer, 2018).

Potato production is largely carried out by smallholder farmers, occupying land between 0.5 -1.8 acres (Minten et al, 2010). Farmers who grow potato for household consumption are typically vegetable farmers and use kitchen gardens for production (RACP, 2013). Due to its heavy water requirements, potato cultivation is mainly during the summer or rainy season in the mid and high hill areas. Potato can also be produced under irrigation in the valley and low hilly areas during autumn (RACP, 2013). Over the last decade, India recorded increased growth rates in production area, productivity, and production value. In 2013, India produced 45.34 million tons of potatoes, 12.32% of the world's production (Rana & Anwer, 2018).

Most farmers rely on their own stored potato seed, thus little reliance on seed markets. In Bihar, less than 20% of sampled potato plots

4 In India, a literate person is defined as one who can read and write a simple message in any language with understanding. People of age > 7 years are included in the statistic.

5 GPI is the ratio of the number of females enrolled in all education levels corresponding to the number of males. A GPI between 0 and 1 implies a disparity in favour of men, while that which is > means a disparity in favour of women.

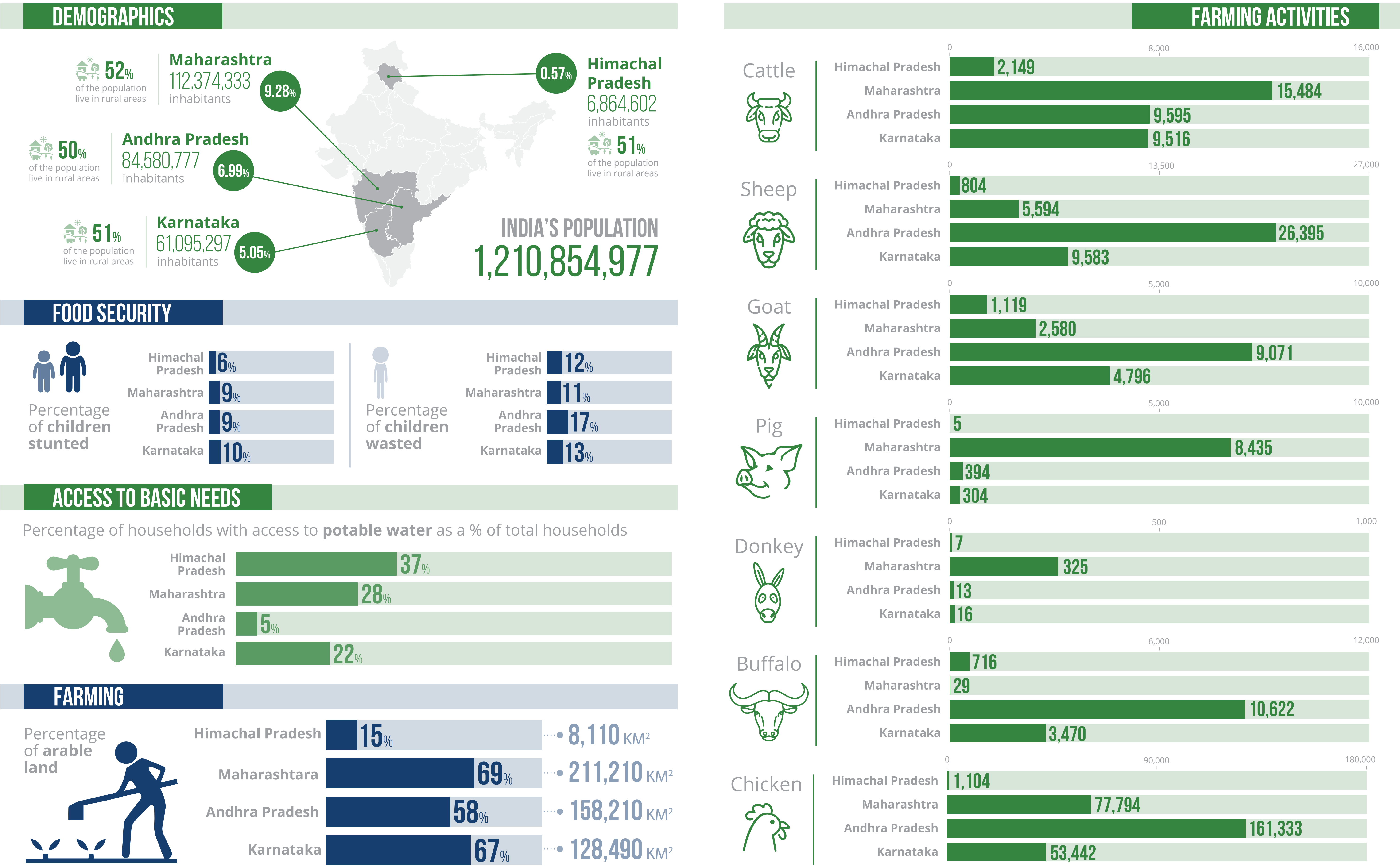
6 An agro-climate zone is defined as a land unit in reference to major climates that are suitable for a certain range of crops. India has 15 agro-climate zones in total.

7 A lakh is a unit in India that is equated to 100,000.

8 Generally, India is characterized by traditional organic farming systems. About 80% of farmers use locally available resources like saved seeds, animal waste, forest litter, and compost. A very small percentage use a minimal amount of inputs (Goverdhan, 2015).

9 India is currently undergoing a process called agricultural feminization. This process has seen the empowerment of women and increased engagement in agricultural activities compared to men.

Figure 2. Livelihoods and agriculture in India



purchased seeds (Minten et al., 2010). This could be because of technological advancement such as cold storages, where a larger portion of farmers can store their seeds. Farmers market potato crops through the Agricultural Produce Market Committee (APMC), local traders, and food processors (RACP, 2013). Sales are during harvest season and most farmers sell to village brokers. The off-season potato sales are through traders. Farmers, however, rarely engage wholesalers in marketing their potatoes (Minten et al., 2010).

Potato farmers experience reduced incomes due to inadequate post-harvest management technologies, potato waste in the value chain, and flooded markets that result in a price drop during bumper harvests (RACP, 2013). Waste levels in the potato value chain are estimated to be 8% during harvest and 9.3% during the off-season (Minten et al., 2010). It is approximated that 50% of losses can be avoided by putting suitable post-harvest measures in place (RACP, 2013). On-farm post-harvest technology training would promote value addition and increase farmer incomes.

Potato processing in India is still very limited but the industry has great growth potential (Rana & Pandey, 2007). Potato chips are India's leading processed potato product. Other products are available such as potato snacks, powder, flakes, and french fries (Dutta et al., 2016). Presently, producers are contract farming with companies like PepsiCo to meet the export demand of processed potato required for potato chips.

2.4.2. Tomatoes

India is the second largest tomato producer in the world. Tomatoes are typically cultivated as a cash crop. Production is concentrated in the Southern and Central states including Andhra Pradesh, Karnataka, Madhya Pradesh, Gujarat, Odisha and Maharashtra, which contribute to the highest tomato production[10] in the country (NHRDF, 2018). Andhra Pradesh is the top tomato producing state and has the largest land area under production. Karnataka is the second highest tomato producing state, has higher productivity than Andhra Pradesh (Ramappa & Manjunatha, 2017), and contributes 4.85% to India's total tomato production (Madhumurthy and Sundaramoorthy, 2018). Tomatoes are grown by all sizes of Indian farm operations. Marginalized farmers who cultivate <1 ha constitute 34% of Indian tomato farmers. Small scale farmers who cultivate 1-2 ha comprise 31% of tomato production. Semi-medium tomato producers who farm on 2-4ha make up 21% of tomato farmers. Medium sized farmers who cultivate 4-10ha constitute 31% of tomato farmers. Finally, large scale operations on >10ha comprise only 1% of tomato producers (Venkat, 2016).

Tomato production was estimated at 800,000 tons between 2016-17 (Madhumurthy and Sundaramoorthy, 2018). The average tomato yield increased over the last decade from 15.90 tons per ha in 2007 to 25.47 tons per ha in 2017. This yield increase is due to better access to inputs, seeds, and new production methods (NHRDF, 2018). For example, high yielding tomato varieties with greater processing suitability were released in the market (Madhumurthy and Sundaramoorthy, 2018). Farmers also increased production by purchasing seedlings from local nurseries, adding chemical fertilizers, and using farm yard manure. Also, 36% of all tomato production is irrigated while 63.6% is rain-fed (Venkat, 2016).

Tomato farmers use various marketing channels. Marketing is through middlemen like commission agents and traders who are found in nearby vegetable markets (NHRDF, 2018). However, the APMC is the major marketing channel. Nonetheless, farmers who sell tomato through Farmer Producer Organizations realized greater profit margins compared to those who sold through other marketing channels (Madhumurthy and Sundaramoorthy, 2018).

10 There are two main tomato growing seasons in India. The kharif season in June to September, and the rabi season in October to February. However, in some regions, tomatoes are produced throughout the year.

Fresh market tomatoes are highly perishable and in response there is growing demand for processed tomato products. Organized retail channels such as supermarkets have also created a market for processed tomato products. Tomato products such as paste and sauce are sold locally and exported to international markets. Big processing companies acquire tomatoes by contracting directly from farmers or buying from wholesalers under APMCs (Ramappa & Manjunatha, 2017). Tomato is also used for culinary purposes such as soups and salads (Madhumurthy and Sundaramoorthy, 2018).

The main challenge in the tomato value chain is post-harvest losses. Major losses, up to 4.8%, are experienced during tomato harvesting. Post-harvest activities like cleaning, grading, weighing, and packaging experience losses up to 6.2%. Transportation creates 2.3% of total tomato losses (NHRDF, 2018). The government, especially Maharashtra, has supported the tomato value chain by subsidizing plastic tomato crates that help reduce transportation losses and costs (Madhumurthy and Sundaramoorthy, 2018).

2.4.3. Apple

India's apple production is the fourth most important fruit crop after mango, citrus, and banana. India has diverse agro-climates and apple production is profitable in hilly states like Arunachal Pradesh, Jammu, Kashmir, Uttarakhand, and Himachal Pradesh. These states account for 95% of total apple production in the country (Wani & Songara, 2018). Production is mainly done on a large-scale, commercial basis. However, there are a few smallholders that grow apples. In 2014-15, apple orchards covered 320,000 ha with an estimated average production of 1,922,000 tons (NIAM, 2018). Despite the fact that Himachal Pradesh is second in apple production, it is known for high quality apple production and is labelled the "*Apple state of India*." Moreover, apple accounts for 46% of total area under fruits, and 88% of the total fruits production in Himachal Pradesh (Wani & Songara, 2018).

The average return on apple production remains low despite large land holdings and high production value. Lack of access to inputs such as quality planting material, farming equipment, chemicals, and irrigation infrastructure attribute to low returns. Planting materials are acquired from accredited nurseries (NIAM, 2018). Apple farmers lack marketing knowledge and depend on middlemen who often give lower market prices compared to prevailing prices (OWFI, 2013). Nonetheless, exportation remains the biggest market for Indian apples. In 2017-18, an estimated 12,500 tons of apples were exported from India. During the same time period, Nepal accounted for 71% of exported apples and Bangladesh 28% (Alvarado & Mishra, 2018).

Apples are primarily consumed fresh in India, which make processing and value addition in low demand. Processors purchase apples from wholesalers or producers and grade them, whereby low graded apples are processed into juice (NIAM, 2018). Other value-added products like jellies and canned apple slices are also manufactured in India.

The most important activities in the apple value chain are sorting, grading, cleaning, packing, and selling (OWFI,2013). The absence of processing facilities at the farm level is the biggest challenge, which often lead to waste and lower prices for farmers (NIAM, 2018). With growing consumer demand for apples there is need for processing infrastructure such as cooling, storage, and cleaning facilities. This is an important step to accommodate the expanding apple market.

2.5. Agricultural sector challenges

Climate change remains a major threat to the sustainability of Indian agriculture and food security. It is likely that India will be negatively impacted by future climatic trends. The country's growing population and dependence on agriculture will only exacerbate greenhouse gases, especially methane from rice cultivation (IARI, 2012). Impacts of climate change such as heat waves, drought, water stress, flooding, and severe storms have proven consequences on farmer livelihoods (NIC, 2009). India's climatic projections show temperatures are expected to rise and extreme rainfall events could lead to flooding. The variability in climate is likely to cause a decline in all major crop yields with rice yields projected to decline by 7% by the year 2050 (IARI, 2012). The GOI needs to implement effective climate adaptation and mitigation measures to salvage agricultural production. Farmers are already using existing knowledge, resources, and experience to manage climatic risks. Soil carbon sequestration has the highest mitigation potential at 89% in India (Mukherjee, 2018). Thus, an increase in carbon sequestration subsidies could incentivize farmers to adopt soil carbon mitigation strategies.

India's agriculture is largely practiced by smallholder farmers. There are 126 million smallholder farmers who own an estimated 74 million ha of land. Smallholder farmers pose a challenge to agricultural production because government extension agencies cannot reach them with support services (Bisht et al., 2020). Smaller landholdings translate to reduced productivity and income among farmers (Iqbal, 2018). India produces 40% less in one hectare of land compared to the US and 50% of farm income in comparison with China. The GOI needs to make smallholder farming economically and sustainably viable through enactment of land fragmentation laws.

Despite the significance of agriculture to India's socio-economic development, its contribution to the GDP is on the decline. Agriculture added 30% to India's GDP between 1990-91 and 14.5% in 2010-11 (Thangamani, 2016). This decline is a result of undeveloped infrastructure that slowed agricultural growth. Poorly maintained irrigation systems and road networks are some of the infrastructural setbacks (Dwivedy 2011). Only 40% of cultivated land in India is irrigated and 140 million ha remain rainfed (Dev, 2008). Currently, year-round irrigation is obtained through conservation of surface and underground water. However, this has been inhibited by water pump power prices.

In addition to poor infrastructure, farming equipment is scarce or too expensive for smallholder farmers to afford. Low technology adoption and higher production costs lead to farm inefficiencies and low productivity (Dwivedy, 2011). Consequently, most smallholder farmers are excluded from services and opportunities offered by the financial sector (Dev, 2008). This is partly due to the political environment that has affected loan waivers and write-offs, which interfere with rural credit institutions. The government therefore needs to invest in rural infrastructure, and intervene on credit markets and agricultural subsidies to incentive farmers.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3. POLICIES, STRATEGIES AND PROGRAMS ON CLIMATE CHANGE

KEY MESSAGES

- India is highly vulnerable to climate change, and a major GHG emitter and polluter.
- In response to this, the GOI formulated the National Action Plan on Climate Change (NAPCC) in 2008 as its independent climate change policy.
- There are also Climate Risk Management (CRM) frameworks to develop and facilitate climate risk assessments.

India is among the most vulnerable countries to climate change due to a rapidly growing population and its limited capacity to deal with the impacts. Over the past decades, the GOI implemented agricultural policies, plans, actions, and frameworks concerning climate change. These changes addressed land use, investment in irrigation, and development and diffusion of new technologies (Goverdhan, 2015).

In response to the Intergovernmental Panel on Climate Change, the GOI formulated the National Action Plan on Climate Change (NAPCC) in 2008 as its first independent climate change policy (Sahu, 2012). Its main objective was to create a comprehensive knowledge system to inform and support climate change action. Other objectives of the NAPCC include improving agricultural sustainability, ensuring equitable distribution of water, and promoting the use of solar energy to reduce GHGs. The National Mission for Sustainable Agriculture was initiated under NAPCC to enhance monitoring, modelling, and networking for climate change. Some objectives of the NAPCC have been successful and others have not. This discrepancy is because their broad approach lacks specifications, whereby some objectives are quantified and oriented towards mitigation and others are purely focused on adaptation.

India is a major GHG emitter and polluter. In 2009, the declaration of the Major Economies Forum (MEF) on Energy and Climate introduced the goal to substantially reduce emissions in India by 2050. In 2011, the Nationally Appropriate Mitigation Action was founded with the aim to reduce waste and GHGs. Thermal use for waste fractions, whose capacity cannot accommodate recycled material was the top priority in waste and GHG reduction. During the same year, the National Innovations on Climate Resilient Agriculture Initiative aimed to promote sustainable production and build climate resilience in rural households.

The Ministry of Environment, Forest and Climate Change (MOEFCC) created a Climate Risk Management (CRM) framework to develop and facilitate climate risk assessments. The CRM also gave a platform for averting, minimizing, and addressing the losses and damages resulting from climate change. Plans like the 2009 State Action Plan on Climate Change were also developed for mapping regional climate vulnerability, examining future projections and implications, and creating a framework for actionable strategies.

Most of the policies and action plans related to climate change began in the past decade and a number have failed to meet their objectives. Policy impacts are yet to be quantified in terms of improved community climate resiliency. Lack of technical expertise, poor co-ordination among intra-governmental departments, a weak monitoring system, and financial constraints pose a major challenge in the efficient implementation of policy objectives (Rattani, 2018). There is a need for functional, efficient, and decentralized institutional structures at a localized level. These institutional structures are best implemented at the state, district, and village levels. Additionally, creation of implementing structures and agencies, financial and technological support, and methodological guidance are a prerequisite for the swift implementation of action plans and policies.

4. GOVERNANCE, INSTITUTIONAL RESOURCES AND CAPACITY

KEY MESSAGES

- The Indian agricultural sector has been supported by public and private sector institutions on issues related to climate change management.
- Particularly, actors in the apple, potato and tomato value chains have benefited from climate change initiatives that has helped increase farm household resiliency.

India has a strong public and private sector engagement in the agricultural sector, including issues related to climate change management. The Ministry of Agriculture and Farmers Welfare (MOA&FW) is mandated with the regulation of the agricultural sector. The Department of Agriculture, Cooperation, and Farmers Welfare coordinates the implementation measures for climate hazards and their consequences. The Extension Division, under the Sub Mission on Agricultural Extension (SMAE) assists in the dissemination of information and knowledge of new agricultural practices. SMAE also provides professional extension services. In coordination with the Indian Agricultural Research Institute (IARI) and the Indian Council of Agricultural Research, the ministry is able to conduct agriculture and climate change research and provide advisory services. The MOEFCC is engaged in environmental and forestry activities including conservation, controlling pollution, afforestation, and mitigation of land degradation.

The GOI, with support from the private sector, is able to increase farm household resiliency. Through GIC, the three value chains benefited from interventions. GIC provided climatically adapted cultivators, introduction new technologies such as solar powered cold stores, a disease detection smart app, and GAP training. The International Potato Centre improved potato farmer access to climate information, introduced new irrigation methods, and created a breeding program for drought and heat tolerant varieties. The Dutch potato cluster has partnered with the Netherlands Embassy to offer quality seeds and on-farm consultancy to potato farmers. Consequently, they facilitated processing and cold storage technologies. Seed companies like Syngenta, Namdhari Seeds Pvt Ltd, and Seminis, previously known as Monsanto, are providing high yielding tomato seed varieties. The Indian Institute of Horticulture Research is developing and field testing high yielding varieties of tomato. The National Horticultural Research & Development Foundation played a significant role in disseminating advanced technologies to tomato farmers. Companies like Karnal Vegetable Producer Limited established a tomato pack house to provide facilities for collection, cleaning, washing, sorting, packaging, cold storage, and marketing.

The National Horticultural Board is the leading institution in the apple value chain. In partnership with state governments, the National Horticultural Board is able to introduce modern technologies to farmers in India's apple growing regions. In addition, the National Agricultural Cooperative Marketing Federation of India helps to grade and market apples through procurement from apple farmers. The GOI, in partnership with the World Bank, implemented the Himachal Pradesh Horticulture Development Project, which played a significant role in increasing apple production through production intensification, improving processing infrastructure, and creating market linkages.


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5. CLIMATE CHANGE-RELATED RISKS AND VULNERABILITIES

KEY MESSAGES

- High temperature, drought, hailstorms, and late onset of rainfall have the greatest impact on agricultural value chains in India.
- Future climatic trends depict a continuity in the variability, and changes in crop suitability.
- Farmers in India have a high perception of climate change, still, there is need to increase awareness through media and extension services.

5.1. Farmers' perceptions on climate change

Farmers are vulnerable to climate change, and are consistently adapting to the changes in climatic conditions (Dhanya & Ramachandran, 2016). Therefore, their perceptions on climate variability and change are necessary to promote successful adaptation and assess factors that influence local adaptation measures. Tripathi & Mishra (2017) maintain that climate change perception is greatly affected by education and awareness, which most farmers lack. However, Ansari et al. (2018) found that 55% of farmers in the North Indian state have a high level of perception regarding climate change parameters such as rainfall, temperature, and dry spells.

Farmers identify climate change parameters such as increasing temperatures, decreasing rainfall, increased dry spells, and late onset of monsoons over the past 20 years (Dhanya & Ramachandran, 2016). Some farmers observe the increase in the frequency of heavy rainfall with it occurring earlier or later than usual. Also, extreme cold has been experienced during the winter season (Ansari et al., 2018) and wind patterns changed (Tripathi & Mishra, 2017). As a result of these climate variations, water tables drastically declined. The perception of climate change impacts varies between women and men. For instance, women perceive increased temperatures to be an inconvenience because they provide field work and are unable to continuously labour in the farms. While men have a perception that winds destroy crops, women are convinced that it destroys housing structures.

Farmers differ in their opinion about the cause of climate change. Some farmers feel that changes occur naturally and others feel that they result from human activities such as reduced rainfall results from deforestation. Even still, some farmers have a low perception of climate change due to inadequate knowledge of adaptation and resilience strategies. Therefore, it is important for farmers to create awareness about climate change and potential adaptation strategies. The media and extension agents play a crucial role in raising public awareness on climate related issues and access to print or digital media should be increased (Tripathi & Mishra, 2017). Nonetheless, public awareness campaigns should focus on youth, small and medium scale farmers, and extension service providers. Awareness campaigns would build national resilience surrounding adverse impacts of climate change on agriculture production.

5.2. Climate change and variability: historic and future trends

Himachal Pradesh is characterized by a temperate climate. The average annual rainfall is 1100mm -1500mm, and the mean temperature is 17°C (Sen et al., 2015). A large section of Karnataka[11] lies in the arid and semi-arid area. This area is characterized by unreliable rainfall, which can be as low as 700mm and as high as 3500mm. It experiences hot and dry summers, with an average high temperature of 34°C. Maharashtra[12] has a tropical climate experiencing summer, monsoon, and winter seasons. Winter temperatures are as low as 12°C while summers have temperatures up to 42°C. Rainfall varies depending on regions averaging 500mm to 2000mm annually. Andhra Pradesh[13] also has a tropical climate throughout most of its regions. Annual temperatures range from 28°C to 40°C with an average annual temperature of 32°C. Rainfall is experienced during the monsoon season but does not exceed 300mm.

High temperature, drought, hailstorms, and late onset of rainfall are major hazards affecting production in the apple, tomato and potato value chains. Thirty year historical[14] data (Figure 2) indicates that India's wettest months are between June and October and the driest months are between November and December. Karnataka observed its highest average annual rainfall in the month of July at 225mm. Maharashtra and Himachal Pradesh also observed their highest average annual rainfall in the month of July at 320mm and 180mm, respectively. Andhra Pradesh experienced its highest rainfall in August at 150mm and October at 180mm. During the first season, the maximum 5-day running average precipitation (Figure 3) in Karnataka and Maharashtra was 32mm and in Andhra Pradesh and Himachal Pradesh it was 26mm.

The 30-year average shows temperatures ranging from 12-35°C in Karnataka, 15-38°C in Maharashtra, and 18-40°C in Andhra Pradesh. Himachal Pradesh has the lowest temperature range from -0 – 22°C (Figure 2). Andhra Pradesh has an average of 70 days with maximum temperature equal to or greater than 35°C, an indication that it is the hottest state. Himachal Pradesh is the coldest state with an average of 5 days (Figure 4). As a result of rainfall and temperature variability, drought is common in India. For instance, the first season indicates an average number of 25 consecutive dry days in Karnataka, Maharashtra, and Andhra Pradesh. Himachal Pradesh has the highest number of dry days, at an average of 37 (Figure 5).

Climatic projections[15] from 2021-2061 show temperature trends, rainfall, and drought are likely to persist in future decades. The maximum 5-day running average precipitation for the four states will increase by 5-7 days, thus increase flood risk (Figure 3). Andhra Pradesh will continue to experience high temperatures with the average number of days above 35°C almost doubling to 108 days. Though Himachal Pradesh will remain the coldest state, it will experience an increase to 16 days above 35°C (Figure 4). While Himachal Pradesh shows an increase of 3 days in the average number of consecutive dry days, the other three states will increase by 10 days by 2031 (Figure 5). This rise in dry days implies droughts will increase in frequency.

11 The climate of Karnataka is available at https://www.karnataka.com/profile/karnataka-climate/
12 The climate of Maharashtra is available at https://en.wikipedia.org/wiki/Maharashtra#Climate
13 The climate of Maharashtra is available at https://www.globalsecurity.org/military/world/india/andhra- pradesh-climate.htm
14 The historical precipitation and temperature trends were analysed using data from CHIRPS (https://www.chc.ucsb.edu/data/chirps), and CHIRTS (https://www.chc.ucsb.edu/data/chirtsdaily)
15 The future projections are an ensemble of downscaled CMIP5 products described (Navarro-Racines et al 2020).

Figure 3. Historical monthly mean temperature and precipitation (average of last 30 years) for Maharashtra State of India. Bars represent total monthly precipitation, whereas lines represent maximum (red line) and minimum (blue line) monthly mean temperatures.

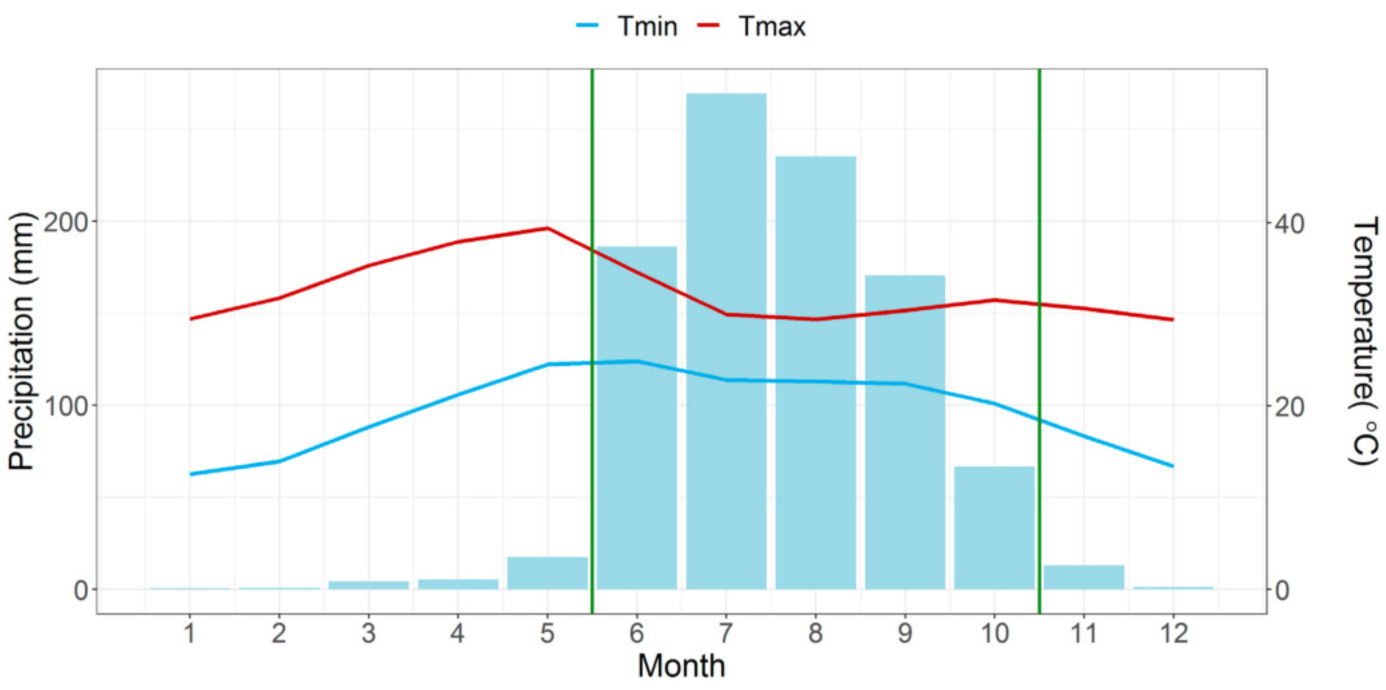


Figure 4. Historical (left), future projected (center), and projected change (right) for the maximum 5-day running average precipitation in millimeters (average of last 30 years) for Himachal Pradesh, Karnataka, Maharashtra and Andhra Pradesh States of India

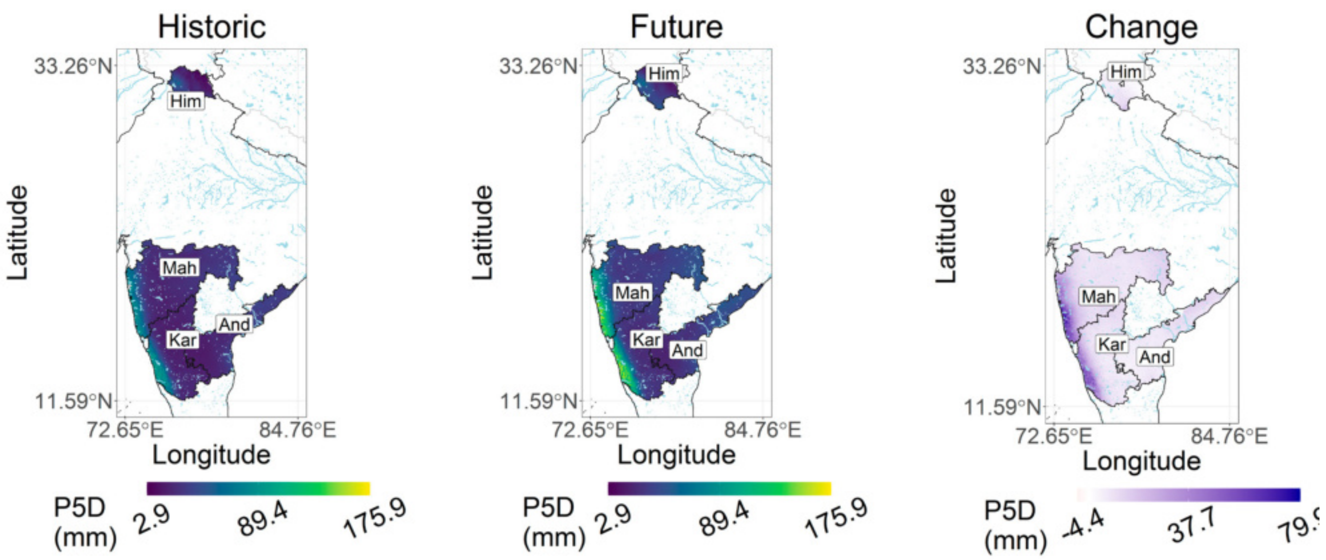


Figure 5. Historical (right), future projected (center), and projected change (right) for the total number of days with maximum temperature greater or equal to 35°C in the year (average of last 30 years) for Himachal Pradesh, Karnataka, Maharashtra and Andhra Pradesh States of India

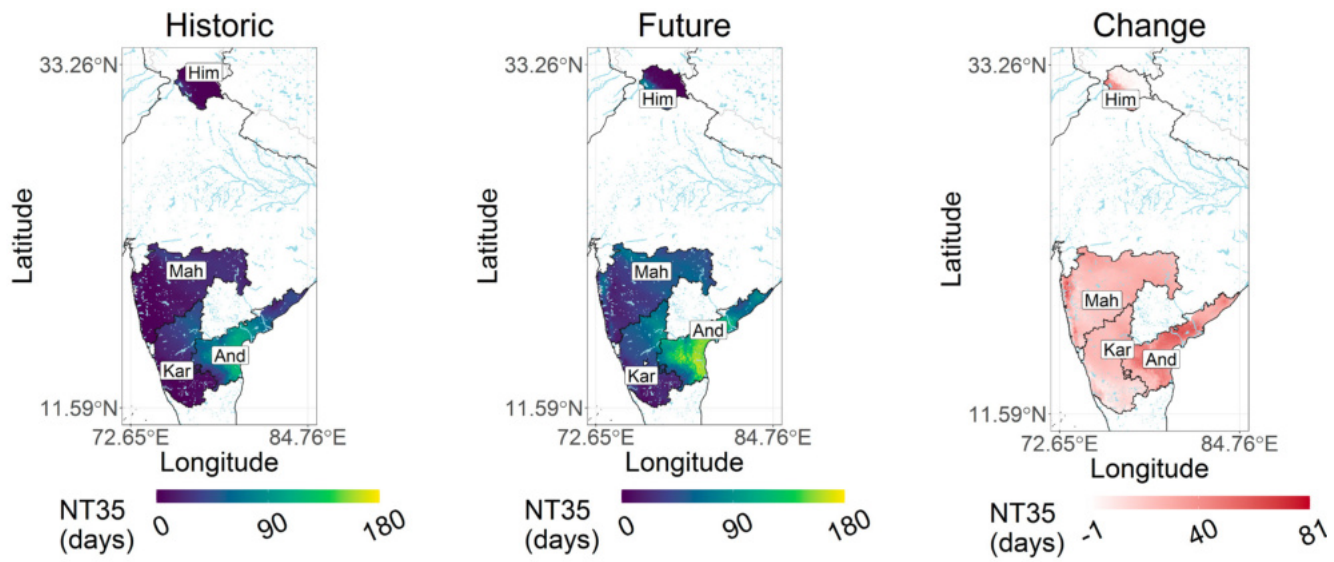
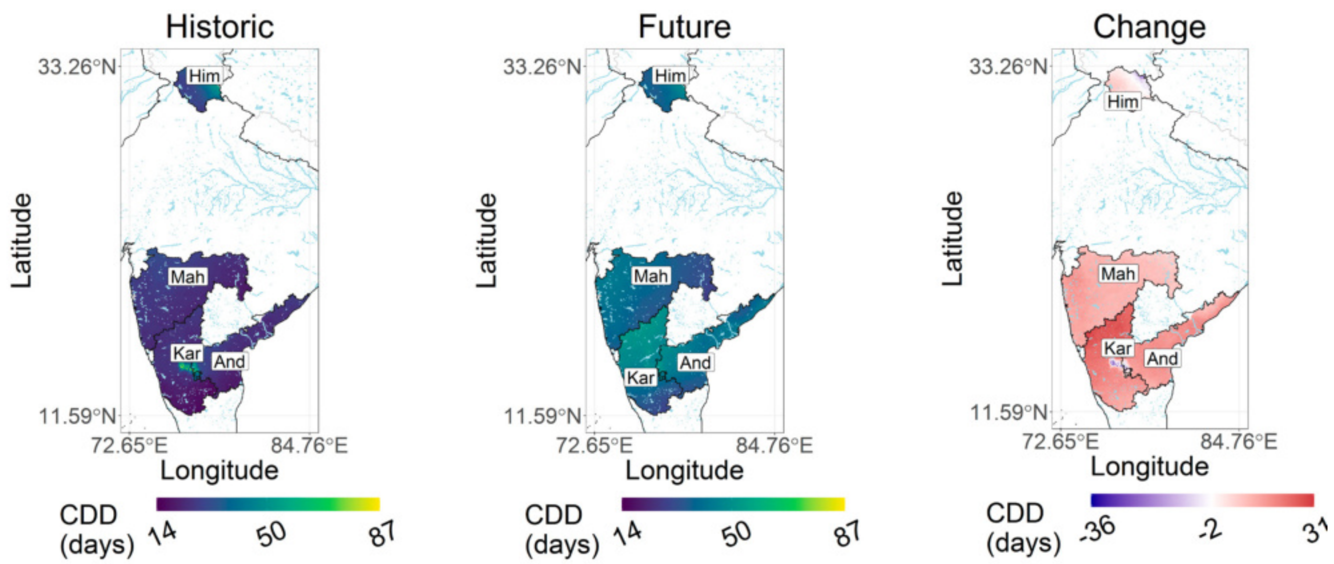


Figure 6. Historical (left), future projected (center) and projected change (right) for the maximum number of consecutive dry days within the year (average of last 30 years) for Himachal Pradesh, Karnataka, Maharashtra and Andhra Pradesh States of India

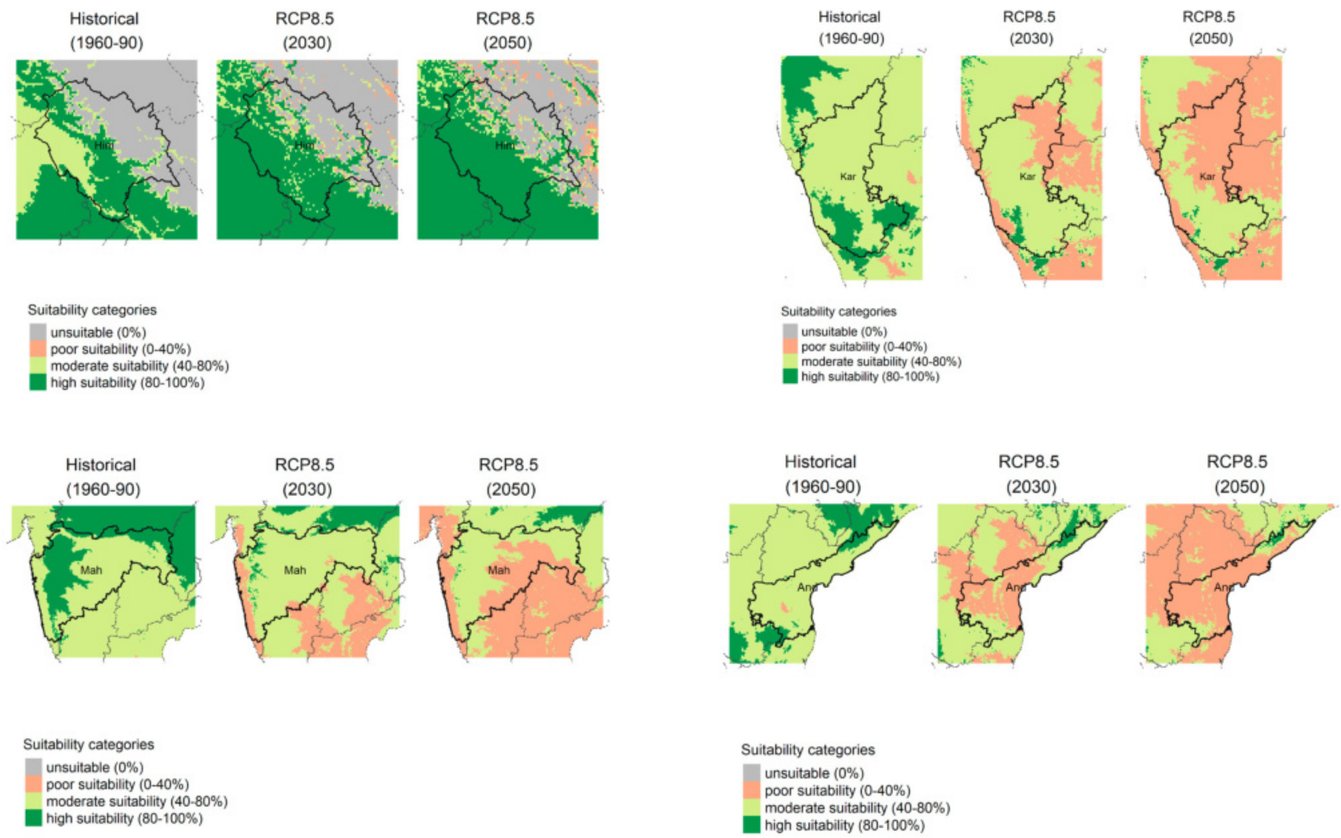


5.3. Crop suitability analysis

A crop suitability[16] analysis shows that between 1960-1990, Karnataka, Maharashtra, and Andhra Pradesh were moderately suitable for potato production. However, suitability in Himachal Pradesh varied from moderate to high, that is between 40-100%. In the same period, the Andhra Pradesh's apple production in the Northern region Pradesh was found to be highly suitable (80-100%), while the Central region had a low suitability (0-40%). Most regions of Himachal Pradesh were highly suitable for tomato and apple production compared to potato. The Western and part of the Eastern parts of Karnataka also had a high suitability for apple and tomato production.

Considering projected climate change scenarios, specifically the temperature increase, India's crop suitability will change in the coming years (Figures 6, 7 & 8). At a Representative Concentration Pathway (RCP[17]) of 8.5, the analysis shows that by 2050, potato suitability will increase in Himachal Pradesh while most of the other three states will not be suitable for production. The apple and tomato producing regions of Himachal Pradesh will maintain their suitability. Andhra Pradesh, Karnataka, and Maharashtra show a decline in suitability in most agricultural production regions. This decline in suitability means that farmers need information on adoption practices and technology to sustain potato production in the future.

Figure 7. Historical and future (scenario RCP 8.5, periods 2030 and 2050) suitability of heat tolerant potato production in the Himachal Pradesh, Karnataka, Maharashtra and Andhra Pradesh States of India



16 Suitability is measured as a specific crop's cumulative percentage of cultivated area. The Eco-Crop model was used to find suitable areas for crop production under current and future climate scenarios (Ramirez-Villegas et al 2013). The criteria used was based on temperature and precipitation thresholds identified by experts.

17 A RCP shows the concentration of Green House Gases (GHG), which indicates global warming by increasing temperatures. Four RCPs are widely used; 2.6, 4.5, 6, and 8.5, whereby a greater RCP represents a higher concentration of GHGs.

Figure 8. Historical and future (scenario RCP 8.5, periods 2030 and 2050) suitability of tomato production in the Himachal Pradesh, Karnataka, Maharashtra and Andhra Pradesh States of India

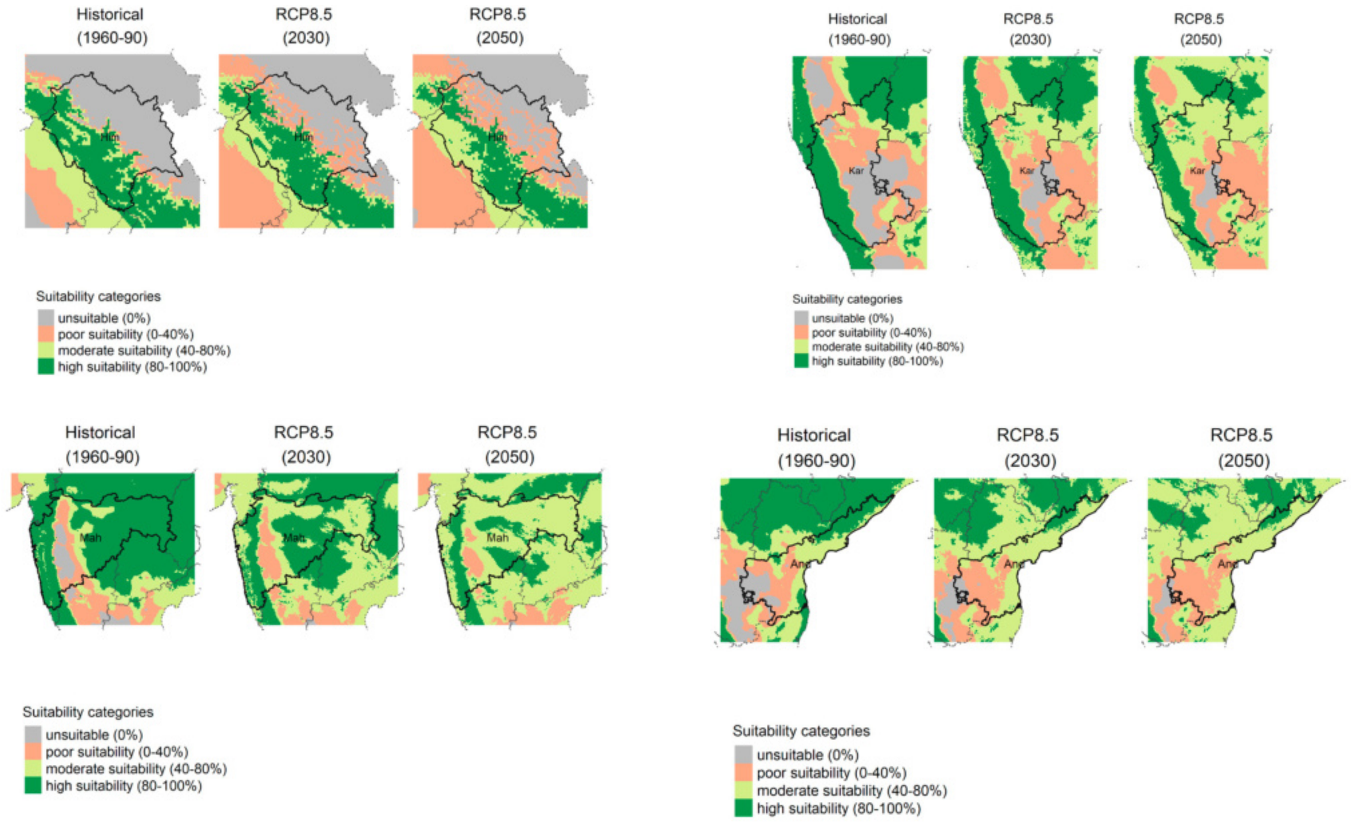
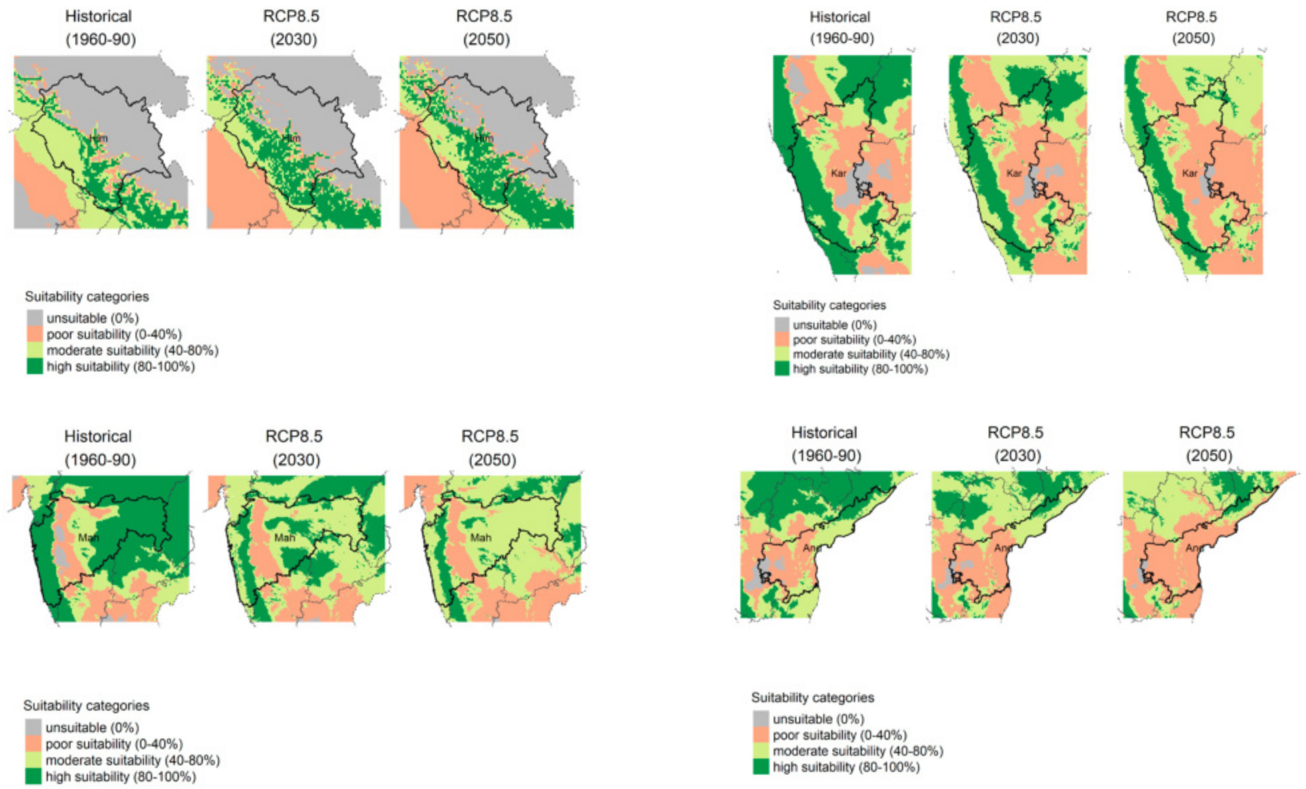


Figure 9. Historical and future (scenario RCP 8.5, periods 2030 and 2050) suitability of apple production in the Himachal Pradesh, Karnataka, Maharashtra and Andhra Pradesh States of India



5.4. Climate vulnerabilities across agriculture value chain commodities

High temperatures, late onset of rains, drought, and hailstorms are the main climatic hazards affecting the potato, tomato, and apple value chains in India. Climate variation impacts on these value chains are summarized in Table 2.

5.4.1. Potatoes

High temperature and late onset of rainfall are the major climatic hazards affecting the potato value chain. Experts[18] agree that the effects of both hazards are greatest during the on-farm and post-harvest stages of the value chain. Potatoes require an average daily temperature between 18 and 20°C and night temperatures < 15°C (Monneveux et al., 2012). Similarly, yields were highest between temperatures of 15 to 20°C. Therefore, temperatures beyond the normal range affect tuber development by slowing germination, growth, and shortening dormancy (Kumar et al., 2015). High temperatures also increase transpiration rates thus raising water requirements that cause stress. Water stress normally leads to declined yields and physiological damage like black spots. By 2050, India's potato yields will decline by 20% if proper interventions are not put in place (Info Resources, 2008). Increased temperature is aggravated by unreliable rainfall. Potatoes require an average of 500 to 700mm of rainfall to achieve a 120 to 150 day growing season (Monneveux et al., 2012). Therefore, prolonged dry weather and delayed rains cause potatoes to desiccate at a younger stage. Desiccation leads to poor quality yields. With changes in climatic conditions, pest and disease incidences increased, specifically late blight and aphids. These incidences pose a threat to seed production (Info Resources, 2008).

5.4.2. Tomatoes

Drought and high temperature are the major climatic hazards affecting the tomato value chain. Experts agree that the greatest impacts are observed in the input acquisition and on-farm production stage. Minimal climate impact is observed on the post-harvest and marketing stages. High temperatures of over 35°C affect the tomato plant's photosynthetic process (Safia,2015), which inhibits fruit development and results in lower productivity. The output from the sown seeds could also decrease by 70%. If temperatures increase by the projected 1.6°C by 2050, India and other top tomato producing countries may lose 30%-100% of their suitable land for production (Litskas et al., 2019). On the other hand, drought stress translates to insufficient water, which leads to delayed tomato root establishment. Stress results in fewer flowers and fruit. Variability in temperature and rainfall causes fungal disease and pests such as the cucumber and fruit fly. Areas growing tomatoes will experience an increase in future pest outbreaks, specifically the two-spotted spider termite (Litskas et al., 2019). Given the current climatic conditions, India's tomato yields will considerably decline in the coming years unless proper mitigation measures are put into practice.

5.4.3. Apple

The climatic hazards that affect the apple value chain are high temperature and hailstorms. The impacts of these two hazards can be severe at the on-farm production stage. Himachal Pradesh is the most affected by increasing temperatures, which cause cracked apples and sun burn that noticeably decrease fruit quality. Regional apple productivity indicates a declining trend of 40-50% in recent years (Singh et al., 2016). Kullu and Shimla, among the major apple producing regions in Himachal Pradesh, observed a 1.2°C temperature increase in the past 25 years (Sen et al., 2015). Increasing temperatures reduce chill units[19] that are crucial for budding. There is a positive relationship between apple productivity and cumulative chill units, therefore, the rise in temperature led to an overall decrease in productivity by 0.4 tons/ha. Wide temperature fluctuation can cause hailstorms, which are experienced in major apple producing regions of India (Singh et al., 2016). Hailstorm damage typically causes apple tree branches to break. Other consequences include inhibiting growth and development at various stages and a vegetative phase that reduces fruit set in the successive season. Climate variability also leads to pest and disease infestation such as apple scab, scale root, and canker. Infestations result in inferior apple quality.

18 The GIZ team identified 20 experts. There were 5 experts interviewed for the potato value chain, 8 for the apple value chain, and 7 for the tomato value chain.

19 A chill unit is the total amount of time that a fruit needs exposure to cold weather for it to break dormancy. It is expressed in chill hours. Apples require <1000 chill units.

6. ADAPTATION TO CLIMATE CHANGE AND VARIABILITY

KEY MESSAGES

- Potato, tomato and apple farmers have benefited from on-farm adaptation strategies to help them sustain their production in the wake of climate change.
- Experts highly rank adaptation strategies oriented towards input maximization, for example, efficient water use and climate tolerant varieties.
- Adaptation is however limited by unreliable weather information, low technology adoption and limited infrastructure.

The effect of climate variability on the potato, tomato and apple value chains has negatively impacted the livelihood and food security of households involved in production. Potential adaptation strategies should focus on efficient water use, tolerant cultivators, timely weather forecasts, and promoting indigenous technical knowledge (Mukherjee, 2018). However, adaptation is limited by unreliable weather information, inadequate credit and marketing facilities, and poor technology adoption. Poor infrastructure such as storage, value addition, and processing facilities are also limiting factors.

6.1. On-farm adaptation strategies

The GIC introduced innovations that help farmers in all three value chains sustain production in the face of climate change. Innovations include the introduction of climatically adapted, disease resistant, and higher yielding varieties. Introduced new technologies include the development of a smart farming app to help detect diseases and advanced weather information. Solar-powered cold stores are in the developmental stages. Farmers are also trained on Good Agricultural Practices (GAP). This is in addition to the government's agri-advisory services whose scale of operation is widespread. In terms of apple production, GICs promote High Density Plantations (HDP) to minimize hailstorm impacts. Nonetheless, there are strategies that are value chain specific as highlighted below (Table 1).

6.1.1. Potatoes

Potato farmers use multiple on-farm adaptation strategies to help cope with climate change effects. For example, the use of low-cost micro-irrigation systems facilitates production throughout the year. Crop diversification and intercropping help reduce vulnerability to weather impacts while mulching enhances organic matter (Info Resources, 2008). The use of improved potato varieties and the adjustment of planting dates are effective in improving potato yields (Kumar et al., 2015). Organic manure application helps to maintain soil fertility. Fungicides and pesticides are sprayed to control for pests and diseases.

6.1.2. Tomatoes

Tomato farmers use a number of coping strategies. The use of organic manure, healthy seedlings, mulch, and spraying of pesticides and fungicides is common among smallholder farmers. Though costly, a few tomato producers practice protected cultivation to shield them against adverse weather conditions. This involves growing tomatoes under controlled environments e.g. under greenhouses (Safia, 2015).

Table 1. Specific practices within each practice group relevant to the focus value chains

PRACTICE GROUPS	POTATO VALUE CHAIN	APPLE VALUE CHAIN	TOMATO VALUE CHAIN
Conservation agriculture	• Mulching		• Compost/manure
Climate services		• Timely access to climate information*	
Water management	• Water harvesting • Precision irrigation*	• Water harvesting*	• Water-saving irrigation*
Disease & Integrated Pest Management	• Smart farming app for disease detection	• Weather-based disease and pest forecasting tools	• Traps • Border crops
Production best practices	• Adjusted planting dates	• Access to training • High density plantations*	• Access to integrated land use training • High quality, healthy seedlings*
Protected cultivation		• Anti-hail nets*	• Protected cultivation*
Variety improvement	• High yield and climatically-adapted varieties*	• High yield and climatically-adapted varieties*	• High yield and climatically-adapted varieties*
Storage and post-harvest	• Solar-powered cold storage	• Solar-powered cold storage	• Solar-powered cold storage • Improved cleaning, sorting, and packaging
Marketing	• Producer groups	• Marketing assistance/ support	
Finance		• Crop insurance	

*Denotes that this is the highest-ranked adaptation strategy for its respective value chain.

6.1.3. Apple

The majority of apple farmers plant low chill and high yielding apple varieties. Apple farmers also practice land-use change. For example, land under apple farming is replaced with coarse grains, seasonal vegetables, and other horticulture crops (Basannagari & Kala, 2013). To enhance production, the use of chemical fertilizers, nurseries, and seedling rootstock is common. Flexible harvest periods are also common, especially during high temperatures. For disease management, farmers use a locally sourced solution known as nila thotha, which is a mixture of diesel, sunlight soap, and copper sulphate. To prevent hailstorm damage, farmers use anti-hail nets (Singh et al., 2016), pruning techniques to remove broken branches, and fertigation through drip irrigation (Bal et al., 2014). There is a growing use of hailstorm crop insurance for sensitive crops like apples. Apart from the national insurance program, almost all states have individual insurance programs. The hailstorm crop insurance is a safety measure capable of protecting farmers' investments (Chattopadhyay et al., 2017).

6.2. Overall ranking of the adaptation strategies

A literature review identified farmers' adaptation strategies. This entailed traditional CSA practices used by farmers, and modern practices introduced by development organizations including GIZ. Similarly, a list of all hazards that affected production in the three value chains was compiled. Experts were then tasked with identifying the two hazards that impacted each value chain the most. Then, the experts chose the two most promising adaptation strategies for each of the two hazards at every stage of the value chain (input acquisition, on-farm production, post-harvest and marketing). All the promising strategies were then ranked on a scale of 1-8, where the value 1 implied a highly-ranked strategy and 8 a low one. The final ranking resulted in two strategies for each hazard in each value chain (See Annexe, Table 5).

The most promising adaptation strategies for the late onset of rain in the potato value chain is the use of climatically adapted varieties (value of 1.7) and precision irrigation (value of 5.3). Precision irrigation includes drip, moisture irrigation, and farm ponds. To combat high temperatures, the use of climatically adapted varieties (value of 1) and adjusting planting dates (value of 2) are ranked highest.

In the tomato value chain, use of quality and healthy seedlings (value of 1) and water-saving irrigation methods (value of 3.5) were highly ranked for dealing with drought. Water-saving irrigation methods include overhead, surface, drip, or sub-irrigation systems. Tomato production under protected cultivation (value of 1) and use of quality and healthy seedlings (value of 4.5) are highly ranked for protection against high temperature. These highly ranked adaptation strategies take into consideration yield potential, adaptability to climate variability, and market acceptance of improved potato and tomato varieties.

For apples, anti-hail nets (value of 1.7) and HDPs (value of 4.8) are highly ranked to combat hailstorms. The use of anti-hail nets is highly preferred because it requires less labour and ensures quality produce. The highest ranked high temperature adaptation strategies include the investment in water harvesting (value of 4.3) and access to timely climate information (value of 4).


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Table 2. Adapting to climate: strategies across major value chain commodities.

POTATOES	INPUT	ON-FARM	POST-HARVEST	MARKETING
High temperature	• Affects seed production, thus unavailability of quality seeds	• Inhibit tuber development • Tuber dormancy (early sprouting) • Increased incidences of pests (aphids) and diseases (Late Blight)	• Reduction in potato yields • Reduced weight of potatoes • Physiological damage (black spots)	• Low market prices due to poor quality • Reduced profits for farmers
Magnitude of impact	MODERATE	MAJOR	MAJOR	MAJOR
Promising adaptation strategies	• Use of potato varieties that are climatically adapted • Adjusting planting dates • Precision irrigation e.g. drip			
Late onset of rainfall	• Delay and untimely input use • Viral infection for tuber seeds	• Unavailability of water • Plant desiccation at younger developmental stage • Increased incidences of pests (aphids) and diseases (Late Blight)	• Poor quality of potatoes • Decline in potato yields	• Low market prices due to poor quality • Reduced profits for farmers
Magnitude of impact	MODERATE	MAJOR	MAJOR	MODERATE
Promising adaptation strategies	• Water harvesting • Use of organic mulch • Precision irrigation e.g. drip • Use of climatically adapted potato varieties			
Strategies to mitigate both hazards				
Farmers coping strategies	• Use of low-cost micro-irrigation systems • Diversification and intercropping • Use of bamboo storage structures • Adjusting planting dates • Early potato harvesting • Mulching			
Ongoing adaptation strategies	• Introduction of new climatically adapted, disease resistant, and higher yielding potato varieties • Provision of water in periods of drought • Use of solar-powered cold stores for seed • Use of smart farming app for disease detection • Strengthening of producer groups			

TOMATO

TOMATO	INPUT	ON-FARM	POST-HARVEST	MARKETING
High temperature	• High costs of seeds	• Affects fruit growth and development • Inhibits floral initiation • Infestation of pests and diseases	• Yield decline • Lower quality fruits (discoloured) • Indecisive harvesting time • Decay of produce	• Lower prices for tomato
Magnitude of impact	MAJOR	MAJOR	MODERATE	MODERATE
Promising adaptation strategies	• Use of healthy and quality seedlings • Production of tomatoes under protected cultivation • Use of traps and border crops			
Drought	• Delayed planting of tomato seeds	• Fewer flowers and fruits • Infestation of pests and diseases	• Yield decline • Low quality of fruits	• Reduces marketable quantity
Magnitude of impact	MAJOR	MAJOR	MODERATE	MODERATE
Promising adaptation strategies	• Use of healthy seedlings • Use of water saving irrigation methods • Application of compost or organic manure			

Strategies to mitigate both hazards

Farmers coping strategies	• Production of tomatoes under protected cultivation • Fungicide and pesticide spraying • Organic manure application
Ongoing adaptation strategies	• Use of high yielding tomato varieties • Promoting healthy and improved seedlings • Promoting post-harvest activities e.g. cleaning, washing, sorting, packaging • Introduction of new technologies to farmers e.g. cold storage • Organic resources and integrated land use training • Promoting water saving irrigation technologies

APPLE

APPLE	INPUT	ON-FARM	POST-HARVEST	MARKETING
Hailstorm	• Reduction in land area used for production	• Inhibits growth and development • Forceful vegetative phase • Affects fruit set • Damages seedlings	• Poor quality of fruit • Damages fruit	• Lower market prices • Reduced profits
Magnitude of impact	MINOR	SEVERE	MAJOR	MINOR
Promising adaptation strategies	• Growing apples in high density plantations • Use of weather-based disease and pest forecasting tools e.g. plantix • Use of anti-hail nets • Use of varieties that are high yielding and climate resistance (low chill) • Use of crop insurance			
High temperatures	• High costs of seeds (low chill)	• Reduction of chill units • Affects budding • Infestation of pests (scab and scale root)	• Decline in overall productivity • Poor quality of fruit (cracking and sunburn)	• Lower market prices • Reduced profits
Magnitude of impact	MINOR	MAJOR	MAJOR	MINOR
Promising adaptation strategies	• Use of timely climate information • Investing in water harvesting solutions • Development of apple cultivars that are drought and temperature tolerant			

Strategies to mitigate both hazards

Farmers coping strategies	• Planting low chill and high yielding apple varieties • Changes in land-use practices e.g. replacing land under apple farming with coarse grains, seasonal vegetables, and other horticulture crops • Shift in harvest period • Use of the locally sourced solution, nila thotha (mixture of diesel, sunlight soap, and copper sulphate), to protect apple plantations from diseases • Pruning of broken branches • Fertigation (through drip)
Ongoing adaptation strategies	• Planting apple varieties that are high yielding and climate resistant • Use of HDPs • Establishment and improvement of apple nurseries • Pest management, post-harvest handling, and GAP farmer training • Use of solar powered cold stores • Use weather-based disease and pest forecasting tool • Assisting farmers in marketing

6.3. Cost benefit analysis of the prioritized adaptation strategies

KEY MESSAGES

» A CBA was computed for one of the highest-ranked innovations in the tomato value chain.

» The use of drip irrigation during drought is associated with increased productivity and profitability

» The risk of investment is however low to moderate due to the high costs of installation, maintenance and operation.

Cost-benefit analysis is critical to make investment decisions, including those associated with CSA practices and innovations. This is because CBA allows for the comparison of costs and returns associated with a given CSA practice when compared to those that already exist[20] in the farm system (Ng'ang'a et al., 2017). In CBA, three indicators[21] are used to show profitability associated with an improved practice or innovation, which are the Net Present Value (NPV), Internal Rate of Return (IRR), and payback period.

In this study, a CBA was computed for the highest-ranked innovations under tomatoes value chain (i.e., using drip irrigation as a water-saving technology). The use of drip irrigation was prioritized because of its potential to conserve water, is less labour demanding and results into a superior yield (when compared to the local variety of tomatoes) per hectare. The adoption of the use of drip irrigation as a water-saving technology requires 36%, 31% and 36% higher capital for installation, maintenance, and operations respectively when compared with the BAU (Table 3). The incremental benefit associated with the use of drip irrigation in tomatoes production emanated mainly from increased productivity (i.e. yield per unit area). This is because there was about a 52% increase in the tomatoes yield per hectare when the drip irrigation is used (Figure 9).

The NPV associated with implementing drip irrigation in the production of tomatoes was on average USD 4,474 per hectare. The average IRR is more than 114%, which is higher than the prevailing discount rate of 6%. The use of drip irrigation had a payback period of about 2.5 years. The risk associated with the use of drip irrigation was assessed using Monte Carlo simulation (n=10000). The results of the distribution of the NPV for use of drip irrigation are summarized in column Table 4. The results show that the profitability risk related to the use of drip irrigation given the characteristics of the cumulative density function of expressing the probability of NPV being less than or equal to the cost of adopting (i.e. implementing, maintaining and operationalizing) drip irrigation is about 37%. This means that the use of drip irrigation for tomato production is profitable, with a low-moderate financial risk for farmers in any given year. The main barriers that farmers are likely to face when adopting drip irrigation practice are high costs installation, maintenance and operations, plus the fact that investment carries a moderate risk of losing invested capital.

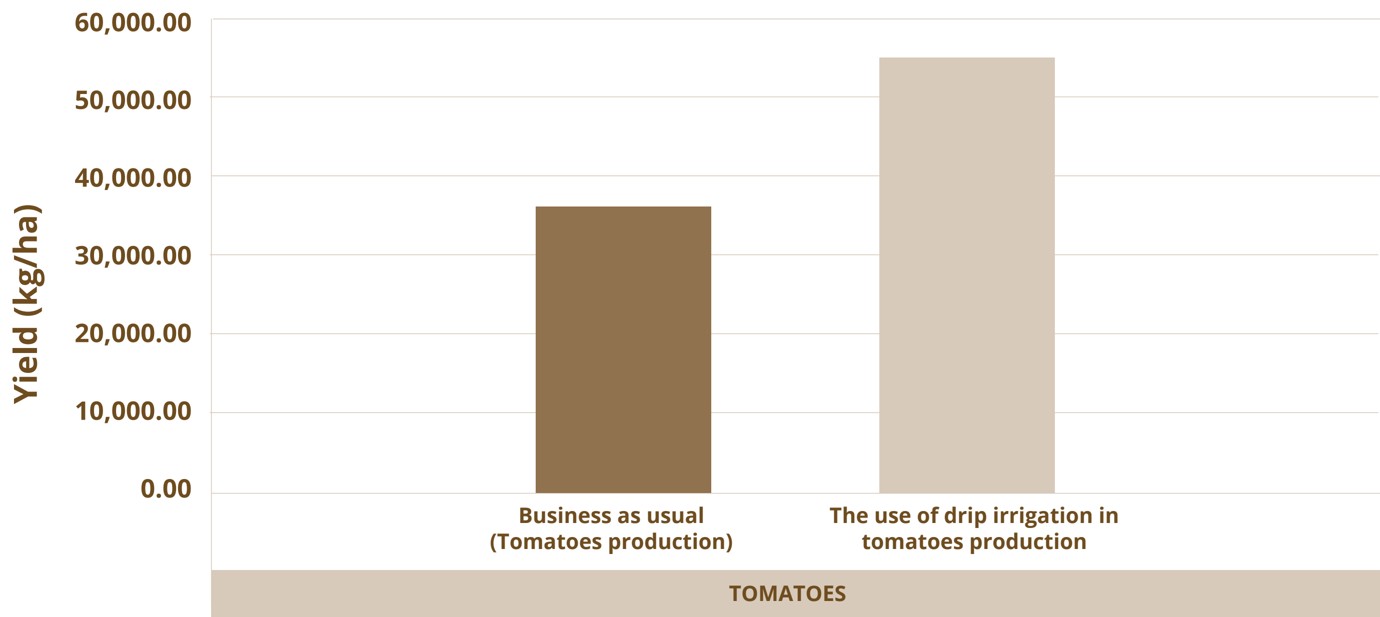
20 The existing practices are referred to as Business as Usual (BAU). Most farmers in the developing world already have conventional practices that help them cope with climate change variabilities. Some of them have been effective while others have had no impact on climate change. Thus, the importance of the comparison.

21 The NPV measures the incremental flow of net benefits from the innovation over its lifecycle, while the IRR is the discount rate that equates NPV to 0. A higher IRR indicates a high profitability potential. Payback period is the number of years it takes to recoup the initial investment.

Table 3. Summary Information on Installation cost for business as usual (BAU) and the use of drip irrigation in the production of tomatoes in India

VALUE CHAIN	INSTALLATION COSTS (US$/HA)		MAINTENANCE COSTS (US$/HA)		OPERATION COSTS (US$/HA)	
	BUSINESS AS USUAL (BAU)	USE OF DRIP IRRIGATION	BUSINESS AS USUAL (BAU)	USE OF DRIP IRRIGATION	BUSINESS AS USUAL (BAU)	USE OF DRIP IRRIGATION
Tomato (Case[22] 1)	1,783.8	2,312.4	6,486.7	8,408.9	763.9	1041.7
Tomato (Case 2)	4,896.5	6,829.2	17,805	23,537	0	0
Average	3,340	4,570	12,145	15,972	382	521
% change when compared with BAU	n/a	+ 37%	n/a	+ 32%	n/a	+ 36%

Figure 10. Yield for Business as usual versus the use of drip irrigation in tomatoes production in India



22 Case refers to responses whereby two experts were interviewed for the tomato value chain (See annex – table 6). The results are therefore reported as the average of the two values.

Table 4. Summary information on profitability associated with the use of drip irrigation in the tomatoes value chain in India

VALUE CHAIN	INNOVATION	PROFITABILITY INDICATORS			
		NPV IN US$	IRR IN (%)	PAYBACK PERIOD (YEARS)	RISKINESS OF INVESTMENT
Tomatoes	Drip irrigation	1,408	91 (>r)	2	This practice has about a 48% probability of making unprofitable returns
		7,540	137 (>r)	3	This practice has about 25% probability of making unprofitable returns

NB: >r implies that the practice is privately profitable per hectare basis

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7. SYNTHESIS AND RECOMMENDATIONS

High temperatures, drought, late onset of rainfall, and hailstorms are predicted to increase in frequency and magnitude in the major Indian tomato, potato, and apple producing states. Due to these climatic hazards, agriculture production systems are at risk of degenerating. This points out to the need of building farmers' capacity to cope with consequences from climate variability. Currently, notable efforts to increase the adaptive capacity of households are evident. On-farm strategies are already being implemented, for example, water harvesting, precision irrigation, use of climatically adapted cultivators, HDPs, anti-hail nets, adjusting planting dates, protected cultivation, and the use of healthy and quality seedlings. Off-farm services such as provision of timely climate information, and new technologies like the development of a weather-based disease and pest forecasting tool have made adaptation feasible.

CBA is a very important tool for assessing whether an investment should proceed or not. This is particularly for smallholder tomato farmers who need to invest in innovations that can improve their resilience to climate change, but are resource-constrained. The use of drip irrigation in tomato production exhibits economic benefits now and in the future, and is therefore important for strengthening future household resilience. Further analysis reveals that it is profitable, with a high rate of returns and a short payback period. This could explain why the innovation emerged as a strong choice among stakeholders during the prioritization process. However, when the distribution of the NPV indicator is considered, the use of drip irrigation has a low to moderate risk of being unprofitable, and this could be due to the high implementation, maintenance costs, and operation costs. This implies that if this practice is to be scaled up, it could be financially beneficial, however, there may need to look for avenues through which farmers are supported – financially and technically - especially during the implementation stage to improve water use efficiency to boost the yield per unit even higher. This is key given that GIC is interested in identifying innovations that can produce desirable outcomes for a majority of smallholder farmers in India.

Poor coordination among intra-governmental departments, lack of technical personnel, a weak monitoring system, and low financial capacity are to blame for ineffective policies. Functional and decentralized institutional structures at the state, district, and village levels are crucial for a vast country like India. Efficient implementation of climate initiatives at a localized level require structures and agency establishment along with financial and technical support. In view of the large contributions that women give to the agricultural sector, their involvement in development policies and planning is key. Moreover, women's engagement in training and extension programmes would help build capacity.

Going forward, a variety of opportunities for collaboration, funding, and synergies exist for these practices (Table 5). Several organizations are well positioned to offer general support across many potential activities. For example, the International Potato Centre works in variety improvement, water management, and climate services. Several federal institutions broadly address agricultural climate change adaptation and mitigation, including the Ministry of Agriculture and Farmers Welfare, the Department of Agriculture, Cooperation, and Farmers Welfare, Sub Mission on Agricultural Extension, the Indian Agricultural Research Institute, and the Indian Council of Agricultural Research. The Indian Government is collaborating with several international institutes, such as the German Agency for International Cooperation, the World Bank, and the International Potato Centre, on climate resiliency programming.

Further, several barriers challenge the general implementation of climate-aware policy in India.
Government extension agencies cannot readily reach smallholder farmers with support services, and there is an overall lack of land fragmentation laws. Innovation is slowed by a lack of road networks and unmaintained irrigation systems. Processing facilities, post-harvest technologies, and storage facilities are in need of additional capital, capacity building, and improved infrastructure. The current political environment largely disables rural credit institutions from serving clients in the agricultural sector.

Table 5. Practice-group specific potential strategies and considerations for advancing CSA at scale

PRACTICE GROUP	PARTNERSHIPS	BARRIERS	EXISTING AND POTENTIAL FUNDING**	SYNERGIES**
Climate services	• International Potato Centre	**Farm level barriers:** • Confidence in weather forecasts • Limited access to forecasts **Institutional barriers:**** • Low access to information and extension services	• Public and private interests with good blended finance potential	• Supports efficiency and planning in input provision, production, postharvest transport and processing, and marketing
Water management	• International Potato Centre	**Farm level barriers:** • High water pump power prices • High implementation, maintenance, and operation costs **Institutional barriers:** • Access to financial services • Lack of capital • Poorly maintained irrigation systems and road networks	• Public and private interests with good blended finance potential	• Effective water management reduces erosion and flooding to support productivity and land restoration efforts

PRACTICE GROUP	PARTNERSHIPS	BARRIERS	EXISTING AND POTENTIAL FUNDING**	SYNERGIES**
Disease & Integrated Pest Management	• Government of India • Green Innovation Centers	**Farm level barriers:**** • Knowledge gaps • Financial constraints **Institutional barriers:**** • Inconsistent extension services • Poor financial service availability	• Good potential for green blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Supports both productivity and environmental / land restoration goals
Conservation agriculture		**Farm level barriers:**** • Lack of access to technology • Knowledge gap **Institutional barriers:**** • Inconsistent extension services Poor financial service availability	• Good potential for green blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Supports climate-resiliency and yields, thus improving market stability
Production best practices	• Government of India • Green Innovation Centers • National Horticultural Research & Development Foundation	**Farm level barriers:**** • Knowledge gaps • Financial constraints **Institutional barriers:** • Poor coordination among institutions • Lack of technical personnel	• Good potential for green blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Supports climate-resiliency and yields, thus improving market stability
Protected cultivation		**Farm level barriers:**** • Financial constraints **Institutional barriers:**** • Cross-institutional coordination • Labor-intensive, particularly in extensive systems	• Good potential for green blended finance, using public funds as a de-risking instrument, delivered through cooperatives to support farmer-initiated investments in long-term land productivity	• Supports climate-resiliency and yields, thus improving market stability

PRACTICE GROUP	PARTNERSHIPS	BARRIERS	EXISTING AND POTENTIAL FUNDING**	SYNERGIES**
Variety improvement	• Government of India • Green Innovation Centers • International Potato Centre • Indian Institute of Horticulture Research	**Farm level barriers:**** • Financial constraints • Considerable capital required • Limited availability **Institutional barriers:**** • Inadequate access to inputs • Low access to finance • Knowledge gaps • Lack of research and development and distribution networks	• International research funding offers robust support • Diversification toward local and culturally important crops needed	• Climate-resilient varieties help stabilize harvest quantities, thus supporting stable markets
Storage and post-harvest	• Government of India • Green Innovation Centers • World Bank	**Farm level barriers:**** • Capital constraints • Knowledge gaps **Institutional barriers:** • Poor coordination among institutions • Lack of technical personnel • Suboptimal infrastructure including inadequate access to good roads, cold storage, warehouses, and other conservation technologies**	• High potential for private sector investing	• Reduces losses, thus increasing profits and supporting markets stability, particularly inter-seasonally
Marketing	• National Agricultural Cooperative Marketing Federation • Government of India • World Bank	**Farm level barriers:**** • Poor transportation networks to access markets **Institutional barriers:** • Lack of infrastructure • Poor coordination among institutions	• High potential for private sector investing	
Finance		**Farm level barriers:** • Limited access **Institutional barriers:**** • Poor access to credit; Poor availability of farmer-targeted financial services; Low involvement on private sector	• High potential for private sector investing	• Enable on-farm investments in soil fertility, optimized management techniques, and climate resiliency

** based on literature

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